Parking Space Allocation based on Automatic Negotiation with Vehicle

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***Abstract*—When searching for a place to park their vehicles, drivers want a parking lot with available parking that is close to their destination. While locating a parking lot based on provided information of parking space availability is relatively simple, the parking lot may be full by the time the driver arrives, requiring the driver to search for another parking lot. The time wasted searching for parking spaces is a serious problem in large cities all over the world and causes traffic congestion issues in urban areas. In our study, we predict the capacity conditions of parking lots according to parking lot and driver information, and initiate negotiations between parking lot managers and drivers regarding parking space allocation. When a negotiation is successful, the driver receives an assigned parking space suitable to his/her preference. We used multi-agent technology in our simulation experiment and evaluated the travel times of drivers with and without negotiation.**

I. Introduction

In our study, we assume the introduction of a parking space reservation system and propose a parking space allocation mechanism through which parking lot managers negotiate with drivers regarding available parking spaces.

Drivers look for available parking in parking lots within walkable distance to their destination. Thus, drivers select parking lots according to their specific preferences and confirm availability. However, available spaces are not guaranteed and the parking lot may be full by the time the driver arrives at the desired parking lot. Searching for another parking lot is a great waste of time and has become a serious problem for large cities worldwide. Parking spaces in dense urban areas are in high demand and the search for available parking causes traffic congestion [1]. Technological developments in recent years allow drivers to obtain parking space availability information and select a parking lot in advance [2].

However, if the demand for spaces is high, it is likely that drivers will compete for available spaces [3]. The driver who misses out on a space wastes a considerable amount of valuable time searching for another available parking lot. Therefore, while this parking space availability information is helpful, it does not relieve congestion or save time.

We aim to mitigate traffic congestion with a negotiation mechanism that predicts parking lot congestion according to information about parking space availability, driver destination, and more, and allows parking lot managers to negotiate with drivers for parking space allocation. A manager and driver are represented by a parking lot agent and vehicle agent, respectively. The parking lot agents negotiate with the vehicle agents to direct them to another parking lot when the current lot is predicted to be filled shortly. The vehicle agents use their own preferences to evaluate the suggested alternative parking lot. Thus, the negotiation mechanism assigns each driver a parking lot suitable for that driver's preferences. Also, A data center is represented as an information manager agent to collect and analysis information about the parking lots and drivers. We conducted a simulation experiment to evaluate driver travel time and verify the efficacy of our negotiation mechanism for mitigating traffic congestion.

Our paper is organized as follows: Section II summarizes related parking negotiation systems for parking space allocation. Section III describes our parking negotiation mechanism for parking space allocation. Section IV establishes the multi-agent simulation structure. Section V sets forth the simulation experiment for evaluating our negotiation mechanism and Section VI highlights our conclusions and future research issues.

II. Related Works

Di Nocera et al. [4] endeavored to maximize social welfare by considering not only driver demand, but also city needs. They used multi-agent technology that uses agents to represent parking lot managers and drivers in the same manner as our study. Both agents' utility functions are determined based on multi-attribute utility theory; each agent negotiates with the other for parking space allocation. The parking manager agent, assuming the role of a parking lot manager, selects parking lots according to its own preference and negotiates with the vehicle agent, assuming the role of the driver, for a space in a selected parking lot. The vehicle agent evaluates the suggested parking lot according to its own preference and accepts or rejects it. Di Nocera et al. constructed a web application that allows users to automatically select a parking lot in response to user demand. Moreover, they argue that parking space allocation negotiation can improve social welfare.

Chou et al. [5] conducted effective and efficient parking space assignment by considering parking space supply and demand. They constructed an agent-based system that searches parking lots, negotiates parking prices, reserves parking spaces, and introduces an optimal route from the driver's current position to destination through a parking lot. If a driver inputs current location and destination, a vehicle agent negotiates with each parking lot manager and suggests a parking lot suitable for the driver's preferences considering parking price, distance between the current location and the parking lot, distance between the parking lot and the destination, and parking policies. The driver then receives the shortest path from the current location to the suggested parking lot.

III. Parking Space Allocation based on Automatic Negotiation

A. *information sharing between driver and parking lot manager*

In order for a parking lot manager and driver to negotiate on available parking lots, the driver must receive information about the suggested parking lot. Also, to predict future availability for a parking lot, information about drivers vying for a space at that lot must be provided. In our study, we assume that a data center manages this information.

The driver receives the destination, parking time, and acceptable range information (the distance between the parking lot and the driver's destination that is acceptable to the driver), and parks in the parking lot selected by his/her own preference. The driver sends his/her own information to the data center when he/she departs from his/her origin. The data center selects an optimal parking lot based on the driver's information, calculates the shortest path, and provides the route to the driver.

The parking lot manager operates the parking lot and has information about parking price and parking space availability. If the information is updated when a driver parks in the lot, the parking lot manager sends the parking lot information to the data center.

The data center provides the parking lot manager and driver with the information that is collected from the parking lot manager and the driver on request. However, the information is not provided to the parking lot manager and the driver without providing the driver with the shortest path when an optimal parking lot is selected according to the driver's preference, and parking space allocation information is supplied only when negotiation begins.

B. *negotiation algorithm*

Our goal is to reduce the amount of wasted time and relieve traffic problems by predicting the future congestion states of parking lots and promoting negotiation between parking lot managers and drivers.

Figure 1 provides an overview of coordinated behaviors between a driver, parking lot manager, and the data center in the negotiation. The driver and parking lot manager send updated information to the data center when their information needs to be updated. The data center analyzes the received information on the driver and parking lot, and constantly monitors the current parking lot capacity. If the data center determines that the parking lot will be full in the near future, the data center encourages the parking lot manager to begin negotiating and transmits information about the driver who requested that parking lot and all other parking lots. The parking lot manager receives the order from the data center, chooses an alternative parking lot according to the driver information, and proposes an alternate lot to the driver. The driver evaluates the proposed parking lot based on his/her preferences and accepts or rejects it.

If the data center determines that the parking lot will be filled to capacity in the near future, negotiation of parking space allocation between the driver and parking lot manager commences. If the coordination $s_i - n_i < 0$ permits, the data center prompts the parking lot manager to suggest another parking lot to the driver proceeding to the parking lot, where s_i is the parking space availability of parking lot manager i's parking lot and n_i is the number of drivers intending to park at parking lot manager i's parking lot.

During negotiation, the parking lot manager must suggest an alternative parking lot to the driver if the negotiation is to succeed. When an alternative parking lot is found, the parking lot manager selects the alternative parking lot according to

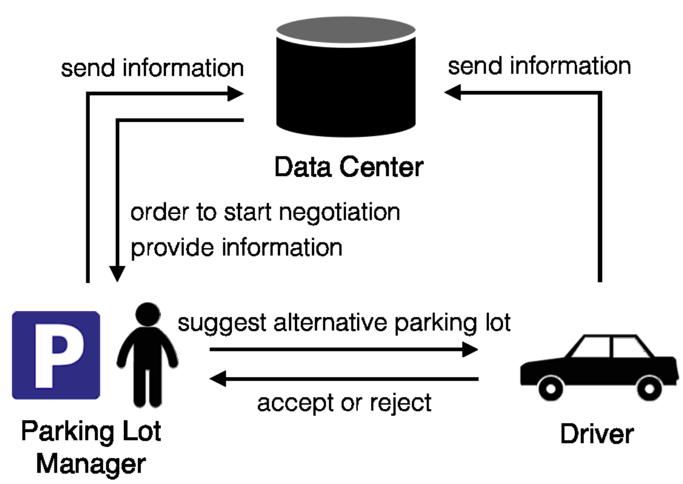

Fig. 1. Overview of coordination between driver, parking lot manager, and data center in negotiation

the information it has received about the driver. Parking lots that are outside of the driver's acceptable range are eliminated as alternative candidates. Then, the parking lot closest to the driver's destination is selected. If no candidate is appropriate, the negotiation will not commence.

The utility of each driver is considered based on the multinominal logit model [6] in the negotiation. Parking lots that the driver originally aimed toward and are suggested by the parking lot manager as alternatives are evaluated according to the driver's utility and the probability of selection is introduced. During the negotiation, the probability of successful negotiation can be defined by equation (1):

$$P_{i,j} = \frac{\exp(U_{k,j})}{\exp(U_{k,j}) + \exp(U_{i,j})}, \tag{1}$$

where $P_{i,j}$ is the probability of successful negotiation between parking lot manager i and driver j, and $U_{i,j}$ and $U_{k,j}$ are the utility function of driver j in the parking lot operated by parking lot manager i and the utility function of driver j in the selected parking lot as an alternative parking lot operated by parking lot manager k, respectively.

The utility of the driver is represented by multi-attribute utility theory [7]. The utility of driver j in the parking lot operated by parking lot manager j can be represented as $U_{i,j} = w_1 u_1^{i,j} + w_2 u_2^{i,j} + ... + w_n u_n^{i,j}$, where w_k is the weight of attribute k and $u_k^{i,j}$ is the utility of driver j in attribute k of the parking lot operated by parking lot manager i. The weight of the attribute always permits $\sum_k w_k = 1$.

In principle, negotiation with the same driver is not conducted. Thus, a parking lot manager who has been refused by a driver cannot renegotiate with the same driver.

IV. Simulation

A. agents

To evaluate the negotiation mechanism's effect on traffic congestion mitigation, we conducted a simulation using multi-agent technology. The parking lot manager negotiates with the driver about parking space allocation and each agent undertakes a series of behaviors through which the driver evaluates the parking lot suggested in the negotiation and behaves according to the result autonomously.

The driver and parking lot are represented by the vehicle agent and parking lot agent, respectively. Also, to conduct negotiation according to the parking lot's space availability, the driver's destination, etc., information is shared between the drivers and parking lot managers. In our study, we assume that the data center shares the information with the drivers and parking lot managers. Thus, the data center is represented by the information manager agent. The detailed behaviors and the role of each agent are as follows:

【*Vehicle agent*】

The vehicle agent has information concerning origin, destination, acceptable range, and parking time. A vehicle agent departs from its origin, parks in the parking lot selected in advance, and proceeds to its destination. The parking lot closest to the agent's destination is assigned to the vehicle agent as the advance-selected parking lot. If an objective parking lot is congested when a driver arrives, we assume that the driver's behavior will be to either wait near the parking lot or go to an another parking lot.

If the driver opts to wait near the objective parking lot, the vehicle agent waits near the parking lot until a parking space becomes available. If another vehicle agent finishes parking and a parking space becomes available, the vehicle agent will immediately park in the unoccupied space.

If the driver goes to another parking lot, the parking lot that is closest to the vehicle agent's destination and has available parking spaces is assigned to the vehicle agent as an alternative parking lot. In the assignment of an alternative parking lot, parking lots that the vehicle agent has already visited are eliminated from the list of candidates. The vehicle agent changes its objective parking lot and searches for routes from its current position to the new parking lot and from that parking lot to the destination. The shortest path is introduced in setting the travel time of the route as a cost.

If the parking lot agent suggests an alternative parking lot during the negotiation, the vehicle agent accepts or rejects this alternative according to its utility function. Equation (1) is used in the evaluation of the vehicle agent's decision. If the vehicle agent accepts, the routes from the current position to the alternative parking lot and from the parking lot to the destination are calculated. In the same way as when a driver perceives that a lot will be full and searches for another parking lot, the route cost is the travel time of the route and the shortest path is calculated. If the vehicle agent rejects the alternative, the vehicle agent continues toward the original parking lot.

The vehicle agent sends its information to the information manager agent when the vehicle agent departs. Also, if the vehicle agent accepts the request to go to another parking lot during the negotiation, the vehicle agent sends this parking lot's information to the information manager agent.

【*Parking lot agent*】

The parking lot agent holds the parking price and parking space availability information. The parking lot agent manages the parking lot information, updates available space information when the vehicle agent arrives, and records the parking time of the vehicle agents. If a space in a parking lot operated by the parking lot agent is 0, the vehicle agent is prohibited from parking in the parking lot.

If the information manager agent predicts that the parking lot managed by the parking lot agent will be full, the parking lot agent starts negotiating with the vehicle agents intending to park at the parking lot agent's parking lot to go to another parking lot according to the vehicle agent information provided by the information manager agent. If some vehicle agents have an acceptable range that is smaller than the distance between the destination and the objective parking lot, negotiation is not initiated. Moreover, the parking lot agent proposes an alternative parking lot according to each vehicle agent's information. In our study, the parking lot agent selects the parking lot that is closest to the vehicle agent's destination from among the parking lots, except for the parking lot managed by the parking lot agent, as an alternative parking lot.

If the information about the parking lot operated by the parking lot agent is updated, the parking lot agent sends its information to the information manager agent. When the vehicle agent arrives at the parking lot agent's parking lot, the parking lot agent updates the vacant space information. In addition, the parking lot agent records the parking time of the vehicle agent.

【*Information manager agent*】

The information manager agent collects, provides, and manages the vehicle agent and parking lot agent's information.

The information manager agent constantly monitors whether the parking lot operated by the parking lot agent will be full in the near future. In the evaluation of future parking space unavailability, as described in subsection III-B, the information manager agent confirms that the condition permits $s_i - n_i < 0$. If the condition is permissible, the information manager agent encourages the parking lot agent to begin negotiations and provides information about the vehicle agent currently proceeding to the parking lot agent's parking lot.

B. simulator

We used SUMO (Simulation of Urban MObility) [8] as a simulator to reproduce the agent dynamics. SUMO is a micro traffic simulator developed by the German Aerospace Center in 2001 as an open-source traffic simulation package. In SUMO, vehicles, public transportation, and pedestrians are modeled as objects. The discrete dynamics of the objects are represented in continuous space; therefore, we can predict and estimate the impact on traffic conditions due to the actions and interactions of the objects.

Using the C++ program, SUMO has high processing power and can visualize the output of the prediction or estimation of traffic conditions in real time. Furthermore, TraCI, which is a client Python library using TCP (transmission control protocol)/IP (Internet protocol) communication, can command SUMO as a server during implementation of the simulation.

The network data of OpenStreetMap, a web platform that provides free geographic data, can be used for creating the data written by the format for SUMO.

In SUMO, the car-following model proposed by Krauß [9] is used to represent the vehicle dynamics. The car-following model defines the velocity of the vehicle in the next simulation step according to the velocity of the vehicle and the preceding vehicle and the distance between the vehicles in the current simulation step.

SUMO can be used by measurement of signal control, route assignment for the vehicle based on a unique algorithm, or evaluation of daily traffic conditions.

V. Simulation Experiment for Evaluation of Negotiation Mechanism

A. simulation settings

In our simulation experiment, to evaluate the fluctuation of time consumption for parking lot searches by the negotiation mechanism, we compared the travel time of vehicles with and without negotiation.

We used the network depicted in Figure 2, which is a network constructed by SUMO according to the geographic data for the center of Nagoya city obtained from OpenStreetMap. There are 12 parking lots in the network. Parking lot agents are created and assigned to the parking lots. 450 vehicle agents are also created and one vehicle agent is poured into the network every 10 seconds.

The origin and destination of each vehicle agent are selected randomly, as the 10 vehicle agents have the same origin and destination from the centroids in Figure 2. The vehicle agents are assigned the following information:

- Acceptable range : 200 m, 400 m, or 600 m
- Parking time : 10 minutes, 30 minutes, or 60 minutes

The acceptable range and parking time for the vehicle agents are selected at random. If the vehicle agents determine that there are no available parking spaces at the objective parking lot when they arrive, the vehicle agents are evenly split to either wait in front of the parking lot or drive toward another parking lot.

The parking lots managed by the parking lot agents are assigned the following information:

- Parking price : 300 yen/hour, 400 yen/hour, or 500 yen/hour
- Parking space availability : 5 vehicles or 10 vehicles

The parking price and parking time of the parking lots are also selected at random. The number of vehicle agents and parking lot agents are equal because the number of agents is equal to the set of origin and destination.

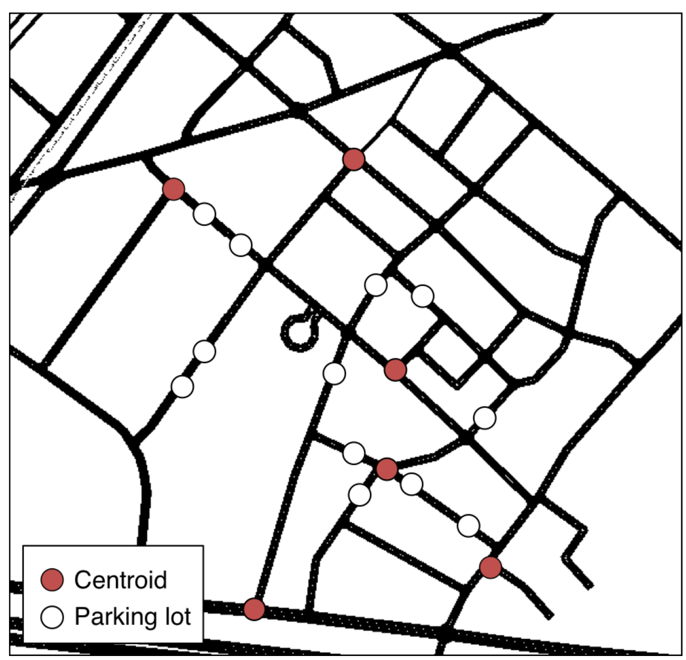

Fig. 2. Network used in the experiment

TABLE I. UTILITY FUNCTION PARAMETERS OF VEHICLE AGENTS IN PARKING LOT [10]

Explanatory variable	Parameter	T value
Walking distance (m)	-0.01875	-18.99
Parking price (yen/hour)	-0.02104	-21.75
Availability information (vacant $= 1$)	5.52917	17.93
Number of vacant spaces (vehicle)	0.08191	5.81
Waiting time (minute)	-0.34511	-13.25

TABLE II. MEANS AND STANDARD DEVIATIONS OF TRAVEL TIME FOR ALL VEHICLE AGENTS WITH AND WITHOUT NEGOTIATION

Case	Mean (min)	Standard deviation (min)
Case1	2851.43	3.95
Case2	3025.06	36.66

Moreover, the utility function of the vehicle agents in the parking lot managed by a parking lot agent can be defined by equation (2):

$$U_{i,j} = w_1 u_1^{i,j} + w_2 u_2^{i,j} + w_3 u_3^{i,j} + w_4 u_4^{i,j} + w_5 u_5^{i,j}, \quad (2)$$

where $u_n^{i,j} (n = 1, 2, 3, 4, 5)$ is the explanatory variable in the utility function of vehicle agent j in the parking lot operated by parking lot agent i, $u_1^{i,j}$ is the distance between vehicle agent j and the parking lot operated by parking lot agent i, $u_2^{i,j}$ is the parking price, $u_3^{i,j}$ is the availability information (if the parking lot has available parking, the value equals 1; otherwise, the value is 0), $u_4^{i,j}$ is the number of vacant spaces, and $u_5^{i,j}$ is the waiting time. In addition, $w_n (n = 1, 2, 3, 4, 5)$ is the utility function parameter. In our study, the parameters are set as shown in TABLE I [10]: $w_1 = -0.01875$, $w_2 = -0.02104$, $w_3 = 5.52917$, $w_4 = 0.08191$, and $w_5 = -0.34511$.

B. results

We divided our simulation into two cases according to whether there was negotiation, implemented the simulation 50 times in each case, and compared the mean and standard deviation of the sum outputs of travel time for the vehicle agents. The comparison results for the mean and standard deviation of travel time are depicted in Figure 3. In Figure 3, the vertical axis represents the sum of travel time for all vehicle agents, case 1 represents results with negotiation, and case 2 represents results without negotiation. The mean and standard deviation of the results are also depicted in TABLE II. In TABLE II, case 1 represents results with negotiation and case 2 represents results without negotiation. The mean is the mean travel time for all vehicle agents and the standard deviation is the standard deviation of the travel time for all vehicle agents. The difference between both of the outputs for the mean travel time for all vehicle agents was approximately 170 minutes and standard deviation of travel time for all vehicle agents was approximately 30 minutes.

These results demonstrate that total travel time can be reduced when parking lot agents negotiate. In comparison with the case without negotiation, the standard deviation with negotiation is small and the reduction effects on travel time with negotiation do not fluctuate dynamically. Thus, introducing negotiation can stably reduce travel time.

Next, we analyzed the mean of the total travel time for each vehicle agent in all simulations. The histogram representing the mean of the sum of travel time for each vehicle is depicted in Figure 4. In Figure 4, the classification in the histogram

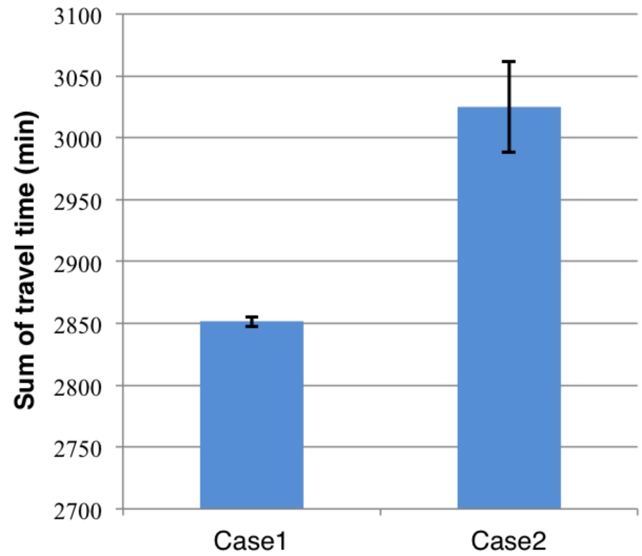

Fig. 3. Comparison of mean and standard deviation of travel time for vehicle agents with and without negotiation

TABLE III. DIFFERENCE BETWEEN TOTAL TRAVEL TIME FOR EACH VEHICLE AGENT AND THE NUMBER OF VEHICLES

Difference in travel time (min)	Number of vehicles
$-8 \quad -6$	4
$-6 \quad -4$	27
$-4 \quad -2$	95
$-2 \quad 0$	136
$0 \quad 2$	105
$2 \quad 4$	62
$4 \quad 6$	20
$6 \quad 8$	1

represents the difference between the total travel time with and without negotiation, the horizontal axis represents the number of vehicles, and the vertical axis represents the classification. The relationship of the classification to the number of vehicles is also depicted in TABLE III. In TABLE III, the difference in travel time represents the classification in the histogram. The analysis reveals that travel time is reduced for 262 vehicles and increased for 188 vehicles. Furthermore, the number of vehicles with reduced travel time increases with the introduction of negotiation.

The overall results of the experiment establish that a parking space allocation mechanism that prompts negotiation can efficiently facilitate parking assignment to drivers and reduce the amount of time wasted searching for a parking lot with available space, thus curtailing overall traffic congestion.

VI. CONCLUSION

Searching for available parking lots creates traffic congestion. Although recent developments allow drivers to obtain advance parking space information, it is likely that drivers will compete for limited parking space availability when the demand for the parking spaces is high.

In our study, we proposed a parking allocation mechanism based on negotiation between the parking lot and driver with the aim of effectively utilizing vacant parking spaces without wasting the driver's time. The data center analyzes

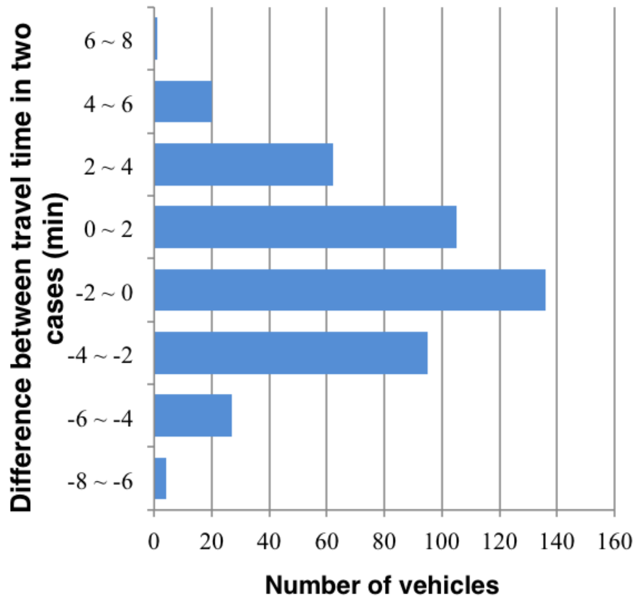

Fig. 4. Difference in total travel time for each vehicle agent with and without negotiation

and observes the future parking space availability conditions according to driver and parking lot information. If it is likely that a parking lot will be full in the near future, the data center prompts the parking lot manager to negotiate with drivers intending to park at the parking lot to go to another parking lot. The parking lot manager receiving the order suggests alternative parking lots to the drivers. The drivers then evaluate the suggested alternatives according to their own preferences and decide whether to accept or reject them.

We verified the effect of introducing parking space allocation based on automated negotiation using multi-agent simulation and compared the outputs of vehicle agent travel time with and without negotiation. As a result of this comparison, we determined that introducing negotiation can assign available parking spaces to drivers and eliminate wasted time and traffic congestion.

Although we can predict the future available space conditions of a parking lot based on the number of vehicles and vacant spaces, future research must examine driver travel time from current position to the objective parking lot, the length of parking time, and other considerations.

Acknowledgments

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